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A STUDY OF THE USE OF METEOROLOGICAL SATELLITE, WEATHER RADAR, --ETC(U)
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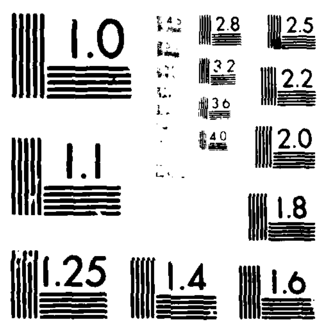

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Report No. FAA-RD-79-92

(12) LEVEL II

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A STUDY OF THE USE OF METEOROLOGICAL SATELLITE, WEATHER RADAR, AND INTEGRATED GRAPHICS PRODUCTS IN THE FLIGHT SERVICE STATION SYSTEM

Dr. T. D. Boldt

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

APRIL 1980

FINAL REPORT

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Prepared for

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16. Abstract

A study was conducted on the use of meteorological satellite imagery, weather radar imagery, and computer-generated meteorological graphics in the automated flight service station (FSS). The present meteorological satellite network and image distribution system is explained. The use of image processing of meteorological satellite imagery was investigated. The National Weather Service, Federal Aviation Administration, and United States Air Force's plans for improved weather were investigated. The use of computer-generated and animated graphics for display of meteorological information was investigated. The study concluded that: 1) satellite imagery could be made available in the near term by utilizing components of the present closed circuit television system; 2) the National Weather Service (NWS) network of WSR-57 weather radars provides the best available information for small area detection and depiction of precipitation; and 3) integration of satellite imagery and weather radar imagery will help the specialist in recognizing and interpreting the information available to him. The study recommended: 1) implementation of present video disc and cathode-ray tube technology for electronically storing, displaying, and sequencing satellite images and NWS facsimile weather charts at FSS's; and 2) various studies as to application of available image processing techniques to meteorological satellite images, application of monochromatic and color displays for satellite imagery, and techniques to automatically derive graphic products from the Federal Aviation Administration Service A circuit.

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METRIC CONVERSION FACTORS

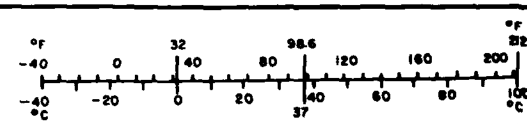
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This study is the result of work requested by Air Traffic Service in a letter dated January 21, 1977. Based upon the study conducted and the conclusions, recommendations are presented to implement that envisioned work.

The purpose of this study is to consider the graphical presentation of satellite imagery, weather radar imagery, meteorological information, and the integration of these in the context of the future automated Flight Service Station (FSS). Also considered were what products could be supplied on an interim basis utilizing the presently installed closed circuit television (CCTV) systems.

The use of satellite imagery in the FSS function was studied to determine how the imagery, and the products derived from the satellite imagery, could improve the specialist's understanding of the aviation weather scene and hence his pilot weather briefing function. Not only were the meteorological satellites studied, but current image processing techniques. It was found that considerable processing of the meteorological satellite imagery is done for scene analysis, but very little pixel-by-pixel analysis is done. Scene analysis here refers to that analysis of the imagery involving major portions of the image (or the entire image). Examples of scene analysis would include wind direction derivation from cloud motion studies, cloud amount and type analyses, and sequencing of images to simulate motion. In contrast, a pixel-by-pixel analysis is done on each picture element (pixel) of the image individually. Examples of pixel-by-pixel analysis are the classification techniques that have been used in the analysis of LANDSAT satellite imagery for land use surveys, forestation studies, geographical, geological, and archeological studies, etc.

The National Weather Service (NWS) weather radar digitization program was investigated for possible use in the future automated FSS. Also, the NWS-proposed next-generation Doppler weather radar was briefly studied. Recommendations are made regarding the Federal Aviation Administration (FAA) use of these NWS weather radar programs.

The use of meteorological graphics in the automated FSS was studied. The manner of presentation of the graphics was investigated in the context of increasing the information assimilated by the specialist in a given time period. It was found that new products could be derived for the automated FSS in a time frame more suited for specialist use than they could be obtained from the NWS.

It was found that the automatic derivation of the products would be necessary in order to supply them at the times necessary for overlay on satellite or weather radar imagery. This integration of imagery and graphics was perceived to provide a dramatic increase in the understanding of significant features of both.

The study also indicated that it would be technically feasible to make available to the FSS specialist, in the near-term, the satellite imagery and limited graphics. The satellite imagery would be derived from the national analog distribution network (commonly known as GOES Tap) and stored on analog disc at the FSS facility. The presently installed CCTV system could then be used for switching, distribution, and display of the satellite images. This would have the advantage over the present paper images of automatic storage and retrieval, sequencing to simulate motion, random access by multiple specialists, and lower maintenance.

Limited graphics could be made available by using the controller resident in the disc for deriving the graphics from the FAA Service A circuit information and the same storage and distribution system as described above for the satellite imagery.

INTRODUCTION

With the projected growth of general aviation in the United States, the demand upon the FSS system for more and better weather briefings will continue to expand. The methods presently employed to distribute and present aviation and meteorological information to the specialist are not adequate for the projected load on the FSS system in the future. For this reason, the FAA is presently formulating and executing plans to automate the FSS.

There are some deficiences in obtaining current weather conditions. The present meteorological information system is dependent upon a network of land-based observation stations which report the meteorological conditions in their immediate vicinity on a scheduled basis. However, there are large areas of the United States which are commonly traversed by aircraft, but which are not covered by qualified weather stations. Also, much of the weather extant within the United States is due to conditions existing outside of the continental borders where observing stations are essentially nonexistant. These deficiencies can be resolved by enhanced coverage.

With the automation of FSS's, there remain the problems of: (1) how to best present the specialist with the obtained meteorological information for rapid and efficient assimilation and interpretation, and (2) how to present the information so that the specialist can formulate in his own mind an overall weather picture and can easily and rapidly distinguish significant aviation weather so that he can recognize weather trends and so advise the pilots.

Weather information will be processed by digital computers, and only significant weather relevant for a particular request will be displayed for the specialist; thus, saving the specialist the time necessary to do this by hand for each and every request. However, the specialist still needs to know the overall weather picture, weather trends, and relevance in order to interpret the information presented to him on request.

Fortunately, the automation of the FSS's offers the means by which solutions to these problems can be developed. Changes to content and format of the information displayed are more readily accomplished by providing the specialist with computer-driven electronic displays. Since the displays are associated with intelligent hardware, it is relatively easy to change the control programs to adapt to improved products. To take advantage of this adaptability, two basic meteorological products, each beneficial, may be added to the system to overcome the problems discussed above and enhance the briefing function. These two derive from two imaging systems; satellite images, both visual and infrared (IR), and weather radar images. Both of these images are necessary for the specialist in that they present him with a visualization of the meteorological conditions extant over a large area and previously only represented by sequence reports, surface analysis maps, and other alphanumeric information. They provide information on those areas not presently served by the network of surface observation reporting stations and for which there is no other source of reliable a priori information for flight briefing purposes. In addition, they represent quantitative information that may be processed and analyzed to obtain meteorological information of importance to aviation. For example, the IR satellite images may be processed and analyzed to produce a cloud-top height map which is currently unavailable by any other means except perhaps through pilot reports. Since the satellite images are updated at a semihourly basis, the information contained is timely and capable of depicting rapidly changing meteorological conditions. Moreover, they provide the specialist with time-gap filler information on the surface observation reporting network which reports conditions hourly.

This report addresses three separate graphics products: satellite imagery, weather radar imagery, and improved meteorological graphics, each potentially beneficial to the pilot briefing function. In order to furnish the specialist useful information, it may be necessary to display these products separately and/or simultaneously.

SATELLITE IMAGERY

Satellite imagery is presently available to user organizations by two separate means. To understand these, some background on how the satellite imagery is obtained and distributed by the National Environmental Satellite Service (NESS) is necessary.

There are two meteorological satellites providing coverage of the United States:

1. GOES-A (Geostationary Operational Environmental Satellite) launched on October 16, 1975, and positioned at 0° latitude and 75° W. longitude.

2. SMS-B (Synchronous Meteorological Satellite) launched on February 6, 1975, and positioned at 0° latitude and 135° W. longitude.

The GOES-A provides coverage for the United States, Canada, and South America. The SMS-B satellite provides coverage of the Western region of the United States and Canada, Alaska, Hawaii, and the Pacific Ocean.

Each satellite utilizes VISSR (Visible and Infrared Spin Scan Radiometer) techniques to register the visual and IR spectrum. There are eight visible radiometers and one IR radiometer. The satellites are spin stabilized and rotated at 100 revolutions per minutes (rpm). The scanning radiometers are stepped to cover the earth in 1,821 steps, one step per revolution, scanning the full earth disc in 18.21 minutes. The resolution of each satellite imaging system is 0.8 kilometer (km) (0.43 nautical mile (nmi)) for the visible spectrum and 8 km (4.3 nmi) for the IR spectrum. The images from each satellite are transmitted in real-time at a rate of 28 megabits/sec to the National Environmental Satellite Service (NESS) Earth Receiving Station at Wallops Island, Virginia, and received via two 18.3 meters (m) (60 feet) dish antennas.

The data are processed at Wallops Island utilizing the satellite position and attitude. During the processing, the images are navigated (i.e., the geopolitical boundaries are overlaid on the imagery) and the data are "stretched" (i.e., the data rate slowed or expanded in time) and transmitted back to the satellite at a rate of 1.75 megabits/sec.

Each satellite acts as a relay for its own "stretched" data transmitted from Wallops Island by retransmitting the data on an omnidirectional antenna. The retransmitted data are commonly termed "stretched VISSR."

At this point, any potential user may receive the "raw" navigated satellite imagery, both visual and IR, for the entire earth disc at full resolution. Utilizing appropriate antenna, preamplifier and receiver, processing equipment, the digital data may be assimilated, the appropriate geographical areas excised, displayed, and/or manipulated as appropriate.

NESS receives the "stretched" VISSR data via two 7.3-m (24-foot) dish antennas located at Suitland, Maryland, and relays the data via microwave link to the World Weather Building in Marlow Heights, Maryland, where the processing equipment is installed. It is here that the appropriate geographical sectors are excised from the data; if necessary the full resolution is degraded and the IR images enhanced. The data are then passed through a digital-to-analog converter and then distributed to the Satellite Field Service Stations (SFSS) at various locations in the United States (figure 1). Each SFSS receives standard sectors of the visual and IR coverage of the United States with resolutions varying from 1/2 nmi to 2 nmi. These standard sectors are then available from the SFSS's to users over their own telephone lines and their own display devices.

The display devices that are presently commercially available are the single-picture (wet or dry) process hard copy print or the TV monitor display with video disc storage and the ability to sequence through a series of images to obtain motion. The later display method is presently available as off-the-

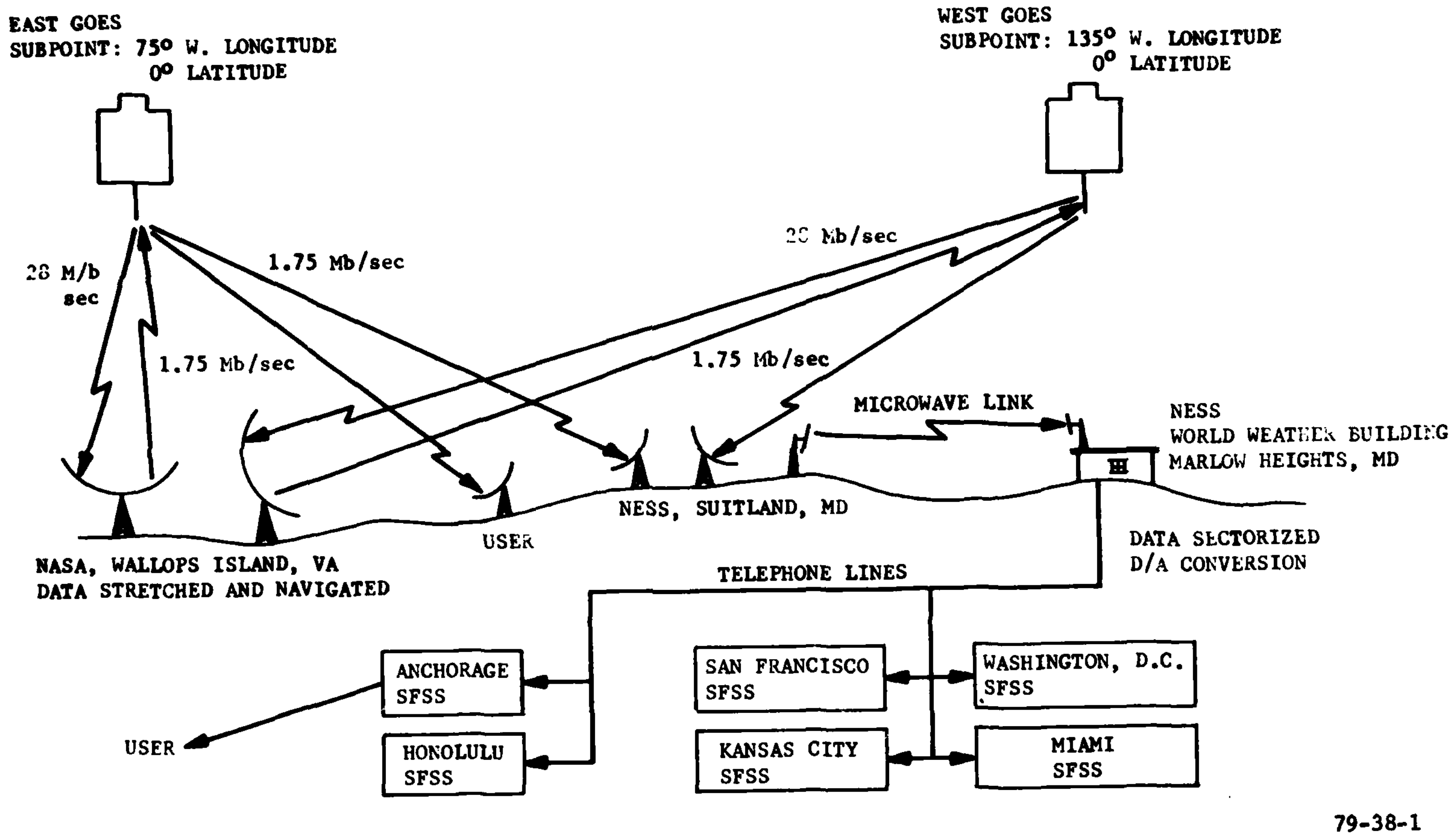


FIGURE 1. NESS DISTRIBUTION NETWORK FOR GOES DATA

shelf equipment. This type of equipment could then be used in the near-term (to 1980) FSS's. The CCTV switching, distribution, and monitoring equipment could be utilized with the video disc to obtain clear satellite images for the specialist on an interim basis.

Each of the two methods for obtaining satellite imagery, digital and analog, has its own inherent advantages and disadvantages. The major advantage of obtaining the "stretched" and navigated digital data relayed by the satellite is the ability to digitally process the image data directly and perform analyses of the meteorological conditions represented. All bits of the encoded images are available without the loss incurred in converting to analog prior to transmittal over the analog communication lines and then reconverting the signal back to digital. Some degradation of the input signal is incurred in each of the above processes, and all losses are accumulative.

Once the satellite imagery has been received and stored, it may be processed. The processing and analysis may vary from the simple requirement of zooming in on any required portion of the image to complex operations involving the luminance of any given pixel and calculating from this, and other known data, information of value to the FSS specialist and the aviation community. An example of the latter operation would be to use the digitized IR image, the satellite IR radiometer calibration, and atmospheric temperature sounding data to calculate cloud tops in feet mean sea level (m.s.l.). This would make available, on a half-hour basis, information which is now only available on a very spotty basis by means of pilot reports. Some of the operations which may be carried out on satellite images are:

1. Sequencing to simulate motion--this depicts for the observer weather trends as they are developing, in a visual manner which requires no mental manipulations to understand.

2. Image Zoom--this requires degradation of the full resolution of the original image so that a large area may be presented on the cathode ray tube (CRT) monitor. As smaller and smaller areas are selected for observation, succesively less and less degradation is required until the image is presented at full resolution. Useful information may also be gained by exceeding the original image resolution in the CRT presentation. Appropriate methods for image degradation and for interpolating beyond image resolution must be investigated for their information content, readability, and visual aspect.

3. Cloud Top Calculation--Utilizing the digital IR image, the IR radiometer calibration and NWS upper air temperature profiles, the data may be analyzed to yield cloud top heights in feet m.s.l. The IR radiometer had an accuracy when installed of $\pm 2^{\circ}$ Centigrade (C) and could be maintained at $\pm 1^{\circ}$ C with very little change in procedure by NESS. The International Standard Atmosphere has a lapse rate of 2° per 1,000 feet of altitude change. Thus, the present calibration level represents an accuracy of approximately $\pm$1,000 feet in a standard atmosphere. The actual accuracy in feet m.s.l. for any given image would depend upon the prevailing lapse rate at the valid time of the image.

4. Cloud Depth Analysis--This type of analysis utilizes the visible data to determine the cloud depth or thickness from the reflected luminance. This work has been pursued on a limited basis and shows promise of incorporation into the FSS data base as the attainable accuracy improves.

5. Separation of Land, Water, and Cloud Masses--This process utilizes the IR data and selects the data into three categories, land, water and cloud, based upon preselected temperature levels. The information may then be displayed using three grey levels or colors. This gives the specialist a concise pictorial display of the geographical distribution of clouds in relation to land and water masses.

6. Filtering--Visual and IR images may be passed through various filters; e.g., Fourier, Hadamard, etc., or the images may have their edges sharpened by derivative operations. Recombination of processed images with the original image and either the IR or visual in a three-color display, offers the ability to emphasize, for the specialist, such features as fog, thunderstorms, high cirrus, etc. The type of sharpening techniques or filtering required to yield the desired information requires further study. The color assignment among the three images which yields the best definition and the most information has yet to be studied and determined.

Other processing techniques that could be applied to both the visual and IR images include principal component analysis, intensity enhancement, data function stretch, contrast enhancement techniques, and change detection techniques. These processing techniques and several under investigation have been used extensively on LANDSAT imagery for geological, hydrological, land use, oceanography, forestry, and related earth resources disciplines. The techniques have not to date been applied in any extensive, systematic analysis of meteorological conditions. Their use in delineating or enhancing significant weather such as thunderstorms, extensive low-level cloud cover, fog, precipitation, etc., should be investigated. Some of the techniques are fairly simple to use while others require extensive analysis of the digitally encoded image. For example, data function stretch involves "stretching" of the grey scale levels present in any image to fill the grey scale levels available for use. For instance, if an image is predominately made up of the lighter (or darker) grey tones, then the darkest grey present is reassigned to black and the lightest grey to white. All intervening levels are reassigned accordingly. The technique is especially useful in distinguishing subtle shading variations as among high- and low-level clouds. The technique may be used on the whole image or any portion of it in which case it is termed a zonal stretch. A much more complicated technique is the principal component analysis. The analysis maps each pixel of the image into an n-dimensional space with axes representing different characteristics of the pixels or image. Once each pixel has been so mapped, new axes are sought to maximize the information content of the remapped pixels. This process is similar to the principal axis transforms of Newtonian mechanics.

Another advantage of utilizing the digital data directly is the availability of the images in near real-time. Approximately 1.7 minutes are required to scan the continental United States and relay the data back through the satellite. The image is then at the processing centers of FSS and may be displayed or processed as necessary. For rapidly changing weather systems, communication and processing time can be very important. In contrast, for the analog data, it requires approximately 26 minutes for sectorization, handling, and transmission of satellite images by the NESS processors at the World Weather Building in Marlow Heights, Maryland. For the analog transmission method, there is then a delay of almost 1/2 hour between the time the image is valid and it is available to the user in the field.

The present GOES radiometers are designed for imaging with one band in the visual and one band in the IR spectrums. The single IR band severely restricts analysis of the earth's atmosphere. NESS and NASA presently have a program for an improved system underway, with the first satellite launch scheduled in 1980. The improved system, VAS (VISSR Atmospheric Sounder), has a radiometer for imaging in one visible band and radiometers for imaging in three bands of the IR spectrum. The 3 radiometers plus 12 filters give an effective 12 bands in the IR spectrum. This greatly increases the possibilities for measuring the characteristics of the earth's atmosphere. By judiciously choosing the IR emittance band of the surface or atmospheric disturbance to be studied with the transmittance characteristics of the atmosphere and the detection capabilities of the IR radiometers, and combinations thereof, it should be possible to detect with greater accuracy the type of disturbance desired. In such a manner, it should be possible to accurately map surface temperatures, low-level atmospheric moisture, and wind direction and speed in cloudless areas. Other applications, such as jet stream detection and clear-air turbulance detection, may become possible as more knowledge is gained about these phenomena and the capabilities of the VAS satellite system.

It is currently planned to launch three VAS systems, one each in 1980, 1981, and 1982. Two would replace the current VISSR systems positioned over the east coast at 75° W. longitude and the west coast at 135° W. longitude, with the third positioned in between somewhere over the Midwest. The two coastal replacements would have expanded capabilities over the VISSR systems, while the third would be used primarily as an atmospheric sounder for specified portions of the continent. It could be used on a scheduled basis to produce soundings of the atmosphere and on a command basis to track atmospheric conditions conducive to storms.

The analog transmission and SFSS network have been in operation for several years. This distribution method is utilized by the NWS weather forecast offices and by several other public and private agencies.

The FAA Central Flow Control Facility (CFCF) in Washington, D. C., has a laser-facsimile receiver for obtaining satellite images from this network. A laser-facsimile receiver was used on a 90-day trial by the Miami FSS. Facsimile images of the 35 NWS weather radars with scan conversion equipment are also available at the CFCF. The meteorologists interviewed at the CFCF preferred the satellite images over the radar images. This preference was due to several factors. Most notable of these were:

1. Clarity of the satellite images as opposed to the radar facsimile images. The satellite images accurately depicted the cloud formations present and so were easier to interpret. Also, the enhanced IR images were utilized and facilitated the interpretation on the visual images.

2. The larger area covered by the satellite images. This facilitated the tracking of hazardous weather and its correlation with the NAS.

The meteorologists at the CFCF regularly used the weather radar facsimile image to indicate the areas of heavy precipitation and then correlated this with both the visual and IR satellite images. These images afforded the meteorologists a very useful visual interpretation of the sequence reports, forecasts, prognostic charts and other analyses available from the NWS. However, for their tracking and short-term prediction of significant weather affecting the NAS, they agreed that the laser-facsimile of the satellite images and the facsimile images of the appropriate weather radar were indispensible. The products available from the NWS were simply too old when received to be of much value for a view of the actual conditions prevalent at the present time and for short-term predictions.

The specialists at the Miami FSS who utilized the laserfax images there also considered the satellite images a valuable tool. The visualization it afforded of the weather conditions improved their understanding of the alpha-numeric sequence reports and the developing weather trends. For locations such as southern Florida, the satellite images were of even more importance as they provided information on areas over the ocean for which no other source oi information existed. The only negative aspects of the installation experienced at the Miami FSS during the 90-day loan derived from two easily correctable situations. First, the laserfax at the FSS was connected into the GOES Tap line drop at the NWS local forecast office. Thus, the specialists were limited in available imagery to that obtained by the forecast office. At times the needs of the specialists did not coincide with those of the NWS meteorologists, and the imagery received was not optimum for the FSS environment. Secondly, the specialists were not trained in the interpretation of the satellite images. They were able to obtain some help from the manual accompanying the laserfax and from visits and discussions with the NWS meteorologists at the forecast office. This second deficiency is already being solved; a course has been initiated at the FAA Academy at Oklahoma City, Oklahoma, for training FSS specialists in satellite image interpretation. The first problem could be easily rectified by a judicious choice of the point from which to obtain a hookup with the GOES Tap for distributing the images to the FSS's.

WEATHER RADAR IMAGERY

The National Weather Service maintains approximately 94 weather radars in their surveillance network as illustrated in figure 2. Fifty-two of these are network radars, mainly s-band, WSR-57's. The remaining are local warning radars. The network radars are operated continuously, while the local warning radars are operated on an as-needed basis to support warning and forecast programs. In the Western United States, the NWS relies mainly upon the FAA ARTCC radars. These are illustrated in figures 2 and 3.

The NWS currently provides radar-derived weather information in four forms: namely, broad band radar (radar video) for direct viewing on a CRT display; textual descriptions of radar weather phenomena originating hourly at radar weather receiving stations and communicated by teletype; the Radar Hourly Summary graphic generated at the Radar Analysis and Development Unit, Kansas City, Missouri, using the textual reports as inputs; and a scan-converted picture of a radar CRT display.

The Radar Summary Chart is prepared and distributed over the facsimile circuit. The production of the graphic is on an as-needed basis. If there is no significant weather to report or no significant change in the reported weather, no summary chart is produced. Instead, the captions on the old chart are updated and it is distributed.

Scan conversion equipment is utilized for the distribution of the weather radar imagery to some FAA ARTCC's, Flight Service Stations, and the CFCF. This equipment makes possible the transmission of an image of the radar CRT display over a voice-grade telephone line simultaneously to receivers anywhere in the country. The National Weather Service currently has 35 radars equipped with scan conversion equipment. The images distributed by this system include operator annotations on echo intensity, movement, height, and other pertinent details.

The images distributed by this technique are generally received on facsimile receiving equipment and suffer from the disadvantages pertaining thereto. They are indistinct and (unless the equipment is very well maintained) tend to be blurred and smeared. The annotations are helpful if they are current, as insufficient detail is available in the facsimile image to interpret the radar returns and determination of factors such as tops are not possible. If annotations are present, the time at which they were made often is not noted on the image, raising the question of their validity.

The National Weather Service has experimented with digitized weather radar in a Digital Radar Experiment (D-RADEX). The D-RADEX equipment was installed at five of the network weather radar sites (Stephanville, Texas; Oklahoma City, Oaklahoma; Monett, Missouri; Kansas City, Missouri; and Pittsburgh, Pennsylvania) as shown by symbol in figure 2. The D-RADEX equipment includes a Nova Minicomputer, cartridge disc drive, and tape unit with other digital and analog hardware. The equipment automatically digitizes the radar image every

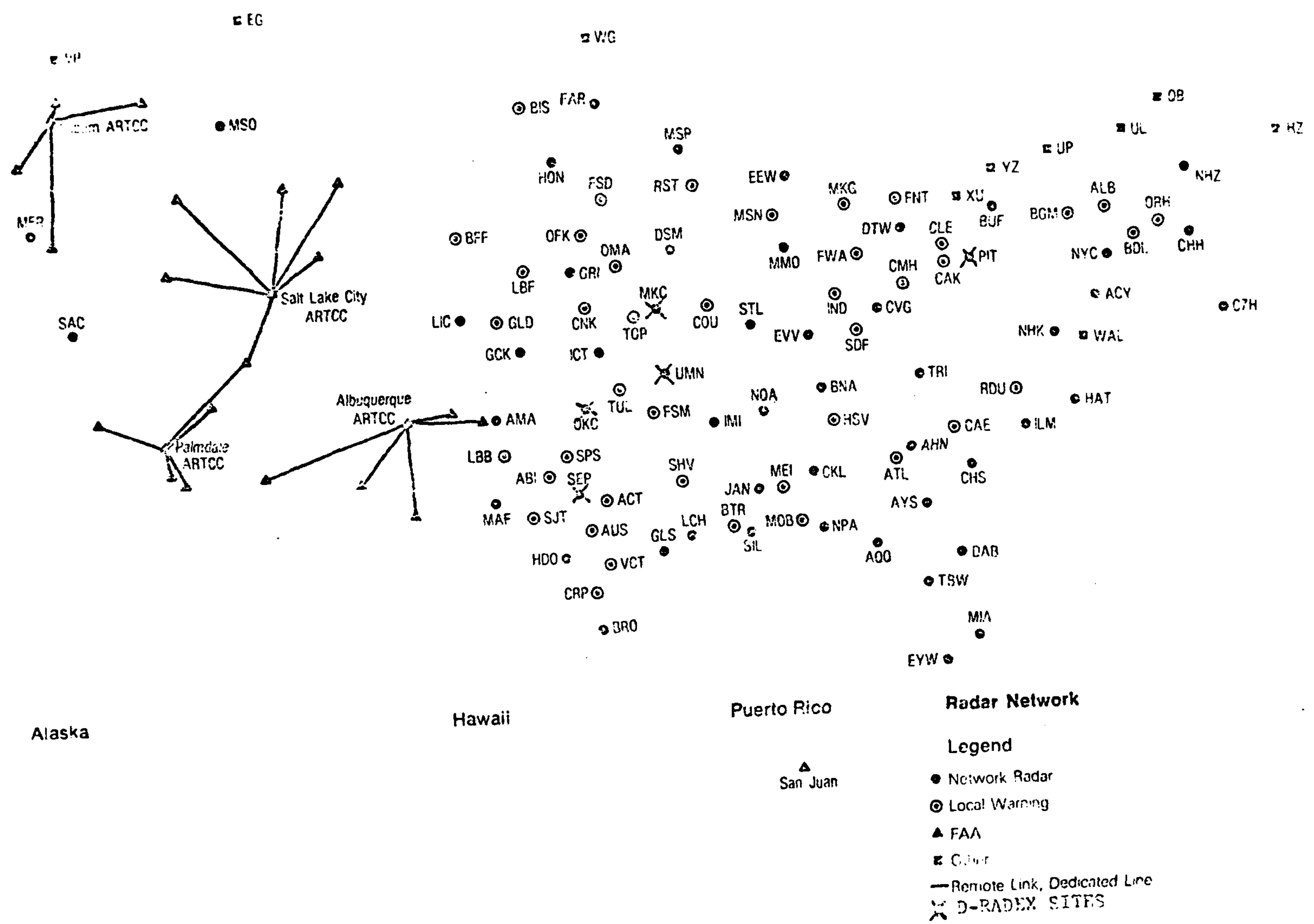
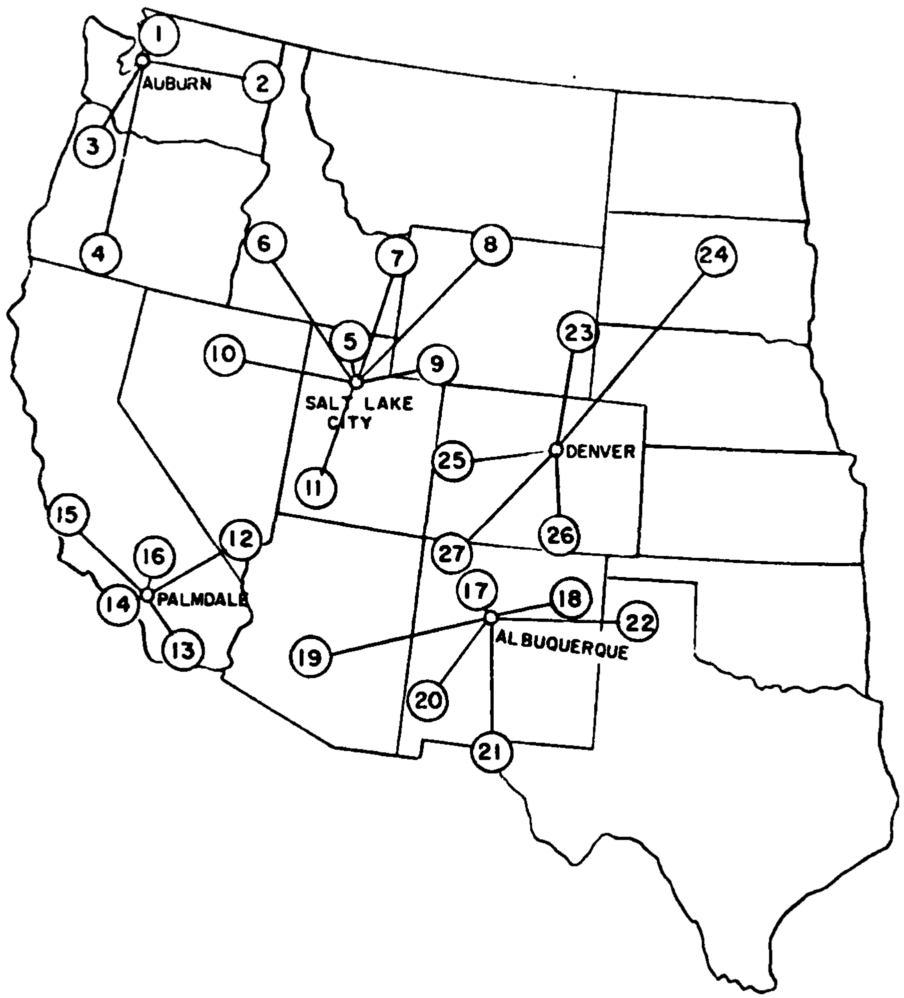


FIGURE 2. NWS RADAR NETWORK FROM NWS D-RADEX MANUAL



	AUBURN ARTCC		**RADAR**
1.	SEATTLE, WA.		ARSR
2.	SPOKANE, WA.		FPS-67B
3.	SALEM, OR.		ARSR
4.	KLAMATH FALLS, OR.		FPS-67B
	SALT LAKE CITY ARTCC		
5.	SALT LAKE CITY, UT.		ARSR
6.	BOISE, ID.		ARSR
7.	ASHTON, ID.		ARSR
8.	LOVELL, WY.		ARSR
9.	ROCK SPRINGS, WY.		ARSR
10.	BATTLE MOUNTAIN, NV.		ARSR
11.	CEDAR CITY, UT.		ARSR
	PALMDALE ARTCC		
12.	LAS VEGAS, NV.		FPS-67
13.	MT. LUGUNA, CA.	(ARSR-3)	FPS-7
14.	SAN PEDRO, CA.		ARSR
15.	PASO ROBLES, CA.		ARSR
16.	BORON, CA.		FPS-67B
	ALBUQUERQUE ARTCC		
17.	ALBUQUERQUE, NM.	(WEST MESA)	FPS-67
18.	MESA RICA, NM.		ARSR
19.	PHOENIX, AZ.		ARSR
20.	SILVER CITY, NM.		ARSR
21.	EL PASO, TX.		ARSR
22.	AMARILLO, TX.		FPS-67
	DENVER ARTCC (Future Expansion)		
23.	LUSK, WY.		ARSR
24.	GETTYSBURG, SD.		FPS-67
25.	GRAND JUNCTION, CO.		ARSR
26.	TRINIDAD, CO.		ARSR
27.	FARMINGTON, NM.		ARSR

FIGURE 3. RADAR TYPES AND SITING

12 minutes. Twice per hour, utilizing an antenna elevation controller, the equipment automatically develops and records a map designating the tops of each echo return area. The D-RADEX minicomputer automatically produces several products from the digitized radar image and tops map information. These products include intensity maps, accumulated rainfall maps, watershed hydrological estimates, tops maps, and a vertically integrated liquid water content (VIL) map. System movement vectors are computed, and a flash flood monitor is maintained.

The maps produced are not exact images of the picture seen on the radar CRT, but rather are processed data presented on east-west, north-south rectangular grids or stereographic map projections utilized by NWS meteorologists. One product produced by the D-RADEX equipment at Pittsburg, Pennsylvania, is shown in figures 4 and 5. The product shown is a radar echo intensity map centered on the radar site.

The D-RADEX is being used by the NWS to develop their digitization techniques and automatically derive products for use in the next generation weather radar, Radar Data Processor (RADAP) which will be of the Doppler type. Utilizing this type of radar, it is anticipated that it will be possible to determine circulations and enable the detection of tornadoes or their generating conditions. The NWS in conjunction with the U.S. Air Force and the FAA (AAT, AAF, ARD-200/400) is currently evaluating a Doppler Weather Radar installation and its applications at the National Severe Storms Laboratory, Norman, Oklahoma.

The National Weather Service is presently formulating plans on how to distribute the automated products now derived by D-RADEX and those to be derived by RADAP. If the automated observations produced by D-RADEX every 12 minutes are distributed within the NWS Automation of Field Operations and Services (AFOS) communications network, then timely weather radar images will be available at the Flight Service Stations for display. At the present time it is not at all certain that the automated radar observations will be distributed by AFOS or if they are, the form in which they will be transmitted. The present output of the D-RADEX is simply too large to be handled by the AFOS communications network. If the NWS finds that it cannot accommodate the digitized radar products within AFOS, then an alternative method of distribution of the automated products must be found.

The processed products, as mentioned previously, are not range-azimuth images as seen on the radar CRT, but a representation on a 3- by 5-nmi rectangular grid. It is unknown how this will affect the usefulness of the product for processing and display to the FSS specialist. If this grid proves to be too coarse for use by the specialist, it will become necessary to find a means of distributing the raw digitized weather radar echo returns to the FSS processing centers.

Once the digital weather radar is available, some of the processing techniques discussed for the satellite imagery could be applied. The

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//I
THRESHOLD: 1
TYPE "A" FOR CROPPED GRID
EAST-WEST MILES: E50-W100
NORTH-SOUTH MILES: N100-S60


PIT  INTENSITY MAP  0900Z, MAR  4, 1976  ANALOG VIP
 ELEV = 0.5  RANGE GATE = 1.0  ANGLE GATE = 2.0
     96  84  72  60  48  36  24  12   0  12  24  36  48
      W...W...W...W...W...W...W...W...*...E...E...E...E

100N         *    1111111211111 * * * * * * *
 95N       *      1111221111111111              *
 90N     *      11122211111111111                   *
 85N   *        11111111212111111
 80N  *         11111122221211111
 75N           11111122222222111 * * * * * *
 70N          *  111222222222211111           *
 65N        *   1 12222222222222111111            *
 60N 1     *      12221122222222211111        12122111
 55N 1    *     1222222332222222221111       112223211
 50N 1   *      222222232223222221111111* *       121
 45N.   *       112111 1112333222111121     11
 40N   *         11111222332212211  11       1 *
 35N             1112222232122111                *
 30N  * 1   111* 111226223211111       -           *
 25N 1      111  1122244211111    11-----           *
 20N 1           1122332221111  * ------- *
 15N         *    122421321111 *  ------- - *        *
 10N         *   1235413321111*  ---------   *
  5N       1111 12333122321     ---     ----
  0*       111233333322111    -----  *  -----11
  5S   11111222311 12111        ---     -----       11
 10S  11112111211   11111     * -------------* 1   ---
 15S 1122121 *  1 11  *        *  -------   * --  ---*
 20S 112211    1111             *     1-  *      --- -
 25S 1122 11  11221    *          * * * *       ------
 30S 32 11    2211      *                      1--1--
 35S 11  1                *                   1--1-
 40S   *     11             *                ---1--
 45S    *  1      *           *             ---  -
 50S     *1 11     *              * * * * *  --
 55S      *          *
 60S       *           *                            *

      W...W...W...W...W...W...W...W...*...E...E...E...E
     96  84  72  60  48  36  24  12   0  12  24  36  48
```

FIGURE 4. D-RADEX INTENSITY MAP, OPERATOR-SPECIFIED AREA OF DISPLAY FROM NWS D-RADEX MANUAL

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//I
THRESHOLD: 1
TYPE "A" FOR CROPPED GRID
EAST-WEST MILES: A

PIT  INTENSITY MAP  0900Z, MAR  4, 1976  ANALOG VIP
 ELEV = 0.5  RANGE GATE = 1.0  ANGLE GATE = 2.0
    120 108  96  84  72  60  48  36  24  12   0  12  24  36  48  60  72
      W...W...W...W...W...W...W...W...W...W...*...E...E...E...E...E...E.

125N                                    11*11*111* * *
120N                              *   1    11 111          *
115N                          *         1  11 111  1            *
110N                       * 1 11 1    111111 111 111111           *
105N                    *  111111111111      11 1     1       11      *
100N                  *    1111111211111 * * * * * * *                1   *
 95N                *      11112211111111111               *
 90N              *      111222111111111111                    *
 85N            *        111111112121111111                       *
 80N           *         11111122221211111                          *
 75N         *          111111222222222111 * * * * * *                *
 70N        *         *  11122222222222211111              *               *
 65N       *        *    1 1222222222222221111111               *
 60N     111 1     *       122211222222222211111          1212211111
 55N    *11111    *      122222223322222222221111         1122232111
 50N    111111   *       22222223222322222111111* *            121     *
 45N   11111    *        112111 111233322211112I          11            *
 40N  *111111  *           1111122233221221I  11          1 *
 35N  * 11111              1112222232122111                    *
 30N  1111111 * 1   111* 111226223211111        -            *        *
 25N  11111111      111  1122244211111     11-----            *        *
 20N  11111111           1122332221111   * ------- *
 15N 11111111*      *     122421321111 *    ------- - *          *        *
 10N 11111111       *    1235413321111*   ---------    *                  *
  5N 1111111      1111 12333122321      ---      ----               *     *
  0* 111122       111233333322111     -----  *  -----11             *     *
  5S 1111111   1111122231I 12111        ---      -----          11*       *
 10S 111111   11112111211    11111    * --------------* 1   ---          *
 15S 11      1122121 *  1 11   *      *    -------    * --  ---*--        *
 20S 22     1112211     1111           *       1-  *       --- --
 25S 111  1111122 11  11221     *         * * * *        --------        *
 30S  111  1132 11    2211       *                      1--1--          *
 35S  * 11    11  1                *                   1--1-
 40S  *        *     11              *                ---1--
 45S   *         *  1       *          *             ---  -            *
 50S              *1 11      *              * * * * *  --              *

      W...W...W...W...W...W...W...W...W...W...*...E...E...E...E...E...E.
    120 108  96  84  72  60  48  36  24  12   0  12  24  36  48  60  72
```

FIGURE 5.   D-RADEX INTENSITY MAP, AUTOMATIC CROPPING, FROM NWS D-RADEX MANUAL

products derived would be in addition to those mentioned previously that the D-RADEX now produces automatically.

The FAA's Aviation Weather Branch in the Systems Research and Development Service (SRDS) is currently studying the use of the D-RADEX--RADAP products and the Doppler radar technique within the context of the Aviation Weather System (AWES). There is currently some question on the adequacy of the D-RADEX products for use within AWES. The study on the usefulness of such products within the FSS environment should await any decisions forthcoming as a result of the research of the Aviation Weather Branch.

METEOROLOGICAL GRAPHICS

The term "meteorological graphics" is used here to denote those graphic products derived from observations of the meteorological conditions extant on the earth's surface and in the upper atmosphere and recorded by conventional immersion observation instruments. These products include but are not limited to these currently produced by NWS and transmitted by teletypewriter and facsimile circuits; e.g., surface analysis charts, weather depiction charts, significant weather prognostics, etc.

All of these products are designed for use on facsimile circuit and around a graphic product on paper. The use of these products with no modification on the electronic display is not utilizing the full potential of such a display. With facsimile distribution it was necessary to group separate products on a single chart, thus reducing the number of products sent over the network. The separate products on a single chart were grouped so as to be compatible, but did not represent the only such grouping. With electronic displays and digital controls, such rigid groupings are no longer necessary, and it is possible to assemble separate charts by varying the combination of graphic products in their makeup. NWS in their AFOS system has adopted this technique. In order to prepare a surface analysis chart as presently used in FSS's, two AFOS graphical products would have to be used. Thus, a meteorologist utilizing an AFOS terminal has many variations available in the charts he may assemble for his analysis.

With electronic displays, it is also possible to vary the format and display technique for graphic products. The display is no longer constrained by the transmission format. In order to optimize the information gained by the FSS specialist in the shortest possible time, the format and display technique may be altered. For example, the surface pressure analysis map may be processed and displayed to the specialist as a projected three-dimensional surface with surface shading. The surface may be rotated in space to conform to special requirements or a standard orientation used. The surface may be color-banded to indicate pressure ranges or alternatively the color bands may indicate surface temperature. Overlaid on this surface, frontal systems may also be indicated. Thus, in one completely new display, the specialist is presented with information from which he may very rapidly discern pressure highs, lows, and troughs and their relation to temperature distribution and frontal systems. The surface may then be animated, utilizing information stored in memory, and the specialist rapidly furnished with trend information. It will be possible to increase the information presented to and assimilated by the specialist by using split-screen techniques. This decreases the time necessary for the specialist to switch from one display to another and also puts all of the information within sight simultaneously. This allows for the specialist to review the salient features of each product and integrate them faster.

Utilizing the FSS processing centers, it will be possible to process, distribute, and display meteorological graphics for the FSS specialist in a more timely fashion. Examples of such processing and distribution could be a nephanalysis (amount and height of clouds), a temperature-dewpoint difference (thus indicating the possibility of fog), etc. The analysis would be accomplished from information collected through the FAA Weather Message Switching Center (WMSC), Kansas City, Kansas, and available at the FSS processing center where algorithms could be added to automatically produce the desired analyses on an hourly basis. When processed and distributed to the FSS's, the specialists will have available current information in graphic form. Other such products currently produced by the NWS, and products not produced by the NWS, but applicable to the FSS mission and distributed at intervals of several hours, could be automatically derived in a more timely fashion for use by the FSS specialist. The production of such graphical products should be coordinated through the NWS to assure the validity of the generating algorithms and the products generated and to avoid duplication of effort.

As with satellite images, it is possible to make available the derived products at the FSS in the near-term (to 1980). With appropriate conversion equipment and microprocessors, the hourly sequence reports available on service A could be screened and processed to derive the above graphics and store them for use. The same video disc utilized for satellite images could be utilized for the storage of the graphics. They could then be distributed and displayed for the specialist using components of the existing CCTV systems.

INTEGRATED GRAPHICS

In some instances it may be of benefit to the FSS specialist to combine satellite imagery with radar imagery, or satellite imagery and meteorological graphics or radar imagery with meteorological graphics, or to combine all three. The imagery affords the specialist dramatic visual evidence of clouds or precipitation areas. Combining this visual presentation with analyses of the surface or upper air conditions such as a frontal analysis, isobar, isotherm and/or isotach contours, temperature patterns or other such information would help the specialist in recognizing and interpreting the information available to him. Overlaying the appropriate meteorological graphic or graphics on the satellite or weather radar imagery through the electronic display device relieves the specialist of having to do this mentally and saves him the time necessary to do so. This time may then be more effectively utilized in the analysis of the information presented.

Using a black/white display with grey scale capability, it would be possible to overlay one graphic product on satellite or weather radar imagery. Some graphics would be more suitable due to their composition than others; i.e., they would be more discernible or more easily read by the specialist. Using color displays, it might be possible to overlay more than one graphic product and maintain their readability. Color would make the single graphic more readable when overlaid than the black/white imagery.

For the combination of graphics with weather radar or satellite imagery, it will be necessary to derive products that are not now produced by NWS or not available from NWS at times and intervals required. For example, if isobars are to be overlaid on the imagery, these would have to be derived from the hourly sequence reports since, as discussed previously, the isobar contours available from NWS are issued every 3 hours and are based on information 2 to 3 hours old when issued. This would invalidate their use for overlaying on satellite images only minutes old and updated every 1/2 hour.

SUMMARY OF RESULTS

Satellite imagery provides real advantages to the specialist as evidenced in its use to date by FSS specialists and NAS meteorologists. It offers advantages in providing information not available from other sources and necessary for preflight and in-flight briefings.

On a near-term basis, the satellite imagery could be made available at the FSS by utilizing the switching, distribution, and monitoring equipment components of the presently installed CCTV systems. This equipment in conjunction with video disc storage of the images would make possible the utilization by the specialists of satellite imagery.

The potential for utilization of satellite imagery for meteorological purposes has been severely limited by the absence of any concerted digital analysis of the images. The utilization of meteorological satellite images has been almost exclusively for photo-interpretation. Enhancement processing of the IR data has been limited to the improvement of the capabilities of photo-interpretation. Correct interpretation of the satellite image as a photograph is important, but it is not the only aspect of satellite imagery utilization. Digital image processing can yield results not possible by photo-interpretation alone. Digital image processing has been used in the analysis of LANDSAT imagery for years and has produced a wealth of techniques that could be adapted for use in the analysis of meteorological satellite imagery. In a systematic application of such techniques, new uses for the GOES imagery in detecting and depicting significant meteorological conditions for the specialist are bound to be uncovered and utilized. Two of the processing techniques that have been started on a limited basis with varying degrees of success that could be of value to specialists and pilots are the use of IR images for cloud top analysis and mapping and the use of the visual images for cloud depth analysis.

The VAS and its applications programs being written and tested are designed to detect, analyze, and track atmospheric conditions. These conditions are of immediate and eminent importance to the FAA NAS and its users. The FAA, to date, has had little-to-no input into this vital and important meteorological tool. The FAA should become more active in the present planning being done by NASA and NESS for the VAS Satellite Program.

Satellite imagery is not presently able to depict areas of precipitation or its intensity for the specialist or pilot. In the future, with the introduction of the VAS satellite program, precipitation may be detected. However, the capability would be for broad areas, and the resolution would be fairly coarse. For small area detection and depiction of precipitation, the NWS network of WSR-57 weather radars still provides the best available information. The use of such a radar has been recognized for many years as a valuable tool for the specialist for preflight and in-flight briefing. At present, the only means of remoting the weather radar image to the specialist are by broad band techniques or by facsimile. The former gives the specialist exact reproduction of the radar display as seen by the NWS meteorologist; however, equipment and land lines for the broad band transmission are expensive.

The facsimile receiver is much less expensive, but the images are of poor quality and consequently of very limited use for briefing.

With the advent of radar digitization via D-RADEX and RADAP, the communication of weather radar image will be facilitated. However, there are questions about the utilization of the image. If the NWS retains its present grid system, will it be too coarse for the specialist to use effectively? What is the optimum method or format for display of the image for the specialist? Will the radar tops map give the specialist a true indication of cloud or precipitation tops? These are but a few of the questions regarding the use of the NWS digitized products that must be answered.

The use of the Doppler radar planned for the NWS next generation radar must be fully investigated. What can the added Doppler provide the specialist in his briefing function? Can the Doppler technique accurately and dependably detect circulation? If so, what do those circulations portend? Under what conditions are they significant? Once these questions have been answered and digitized weather radar becomes a standard FSS product available for the specialist, it will provide them current information on the areas of precipitation and turbulence as a minimum. The realization of the potential benefits of the radar will depend upon the work that is done now by the FAA in investigating the Doppler radar and image processing techniques.

The present meteorological graphics products available or planned do not utilize the display medium or control methods available for use in the FSS Automation Program. Neither are the full power of the digital processing and control techniques utilized in that program for providing meterological graphics information. Currently, emphasis on meteorological graphics is given to relying upon the NWS AFOS system to supply the necessary raw and processed data and graphical information. The NWS AFOS system cannot supply all of the products necessary and desirable for a modernized FSS facility in a timely fashion. The NWS has many users and supplies many products suitably tailored for those users, presenting a problem of supply and demand. The demand for individually tailored products far exceed their ability, or the ability of anybody to supply all products in timely fashion. With the modernization of the FSS system, the FAA has available the processors necessary for deriving some products in the time necessary for briefing purposes and in a format more suitable for that purpose. This serves the dual purpose of providing the specialist with current information in a fashion designed specifically for his use and relieves the burden upon the NWS for products which may be derived automatically. However, as stated previously, all operational uses of these products will be coordinated with NWS.

The FAA has a concurrent problem with automation; in order to keep the manpower at current levels, each specialist will have to become more efficient in assimilating, understanding, and disbursing weather information. The first two are prerequisites for the third. In order for the specialist to assimilate and understand the weather information in a shorter time, it will not be sufficient to simply provide him with the same meteorological graphical products he now has available. A different display technology should be utilized. The meteorological graphics product itself must be altered to fully utilize the flexibility of the display medium to present the graphics in a format conducive to rapid correlation and transfer of the information. In this respect, animation for trending, color displays for simultaneously displaying overlaid graphics, split screen techniques to reduce head movement, the presentation of information in three-dimensional surface representations are but a few of the techniques that may be utilized.

Finally, the integration of the satellite image or weather radar image with meteorological graphics presents the specialist with the opportunity for very rapidly correlating information. Further the specialist will be presented with a dramatic visualization of meteorological phenomena that too many times remain only abstractions embodied in lines drawn on maps prepared and distributed by the NWS meteorologists.

CONCLUSIONS

1. Satellite imagery provides real advantages to the specialist as evidenced in its use to date by FSS specialists and National Airspace System (NAS) meteorologists.

2. Satellite imagery could be made available in the near term by utilizing components of the present closed circuit television systems.

3. Digital image processing of satellite imagery could yield results not possible by photo-interpretation alone.

4. The National Weather Service network of WSR-57 weather radars provides the best available information for small-area detection and depiction of precipitation.

5. The flight service station modernization provides the Federal Aviation Administration with the processors necessary to provide the individual weather products necessary for briefing purposes and in a format more suitable for that purpose.

6. Integration of satellite imagery and weather radar imagery will help the specialist in recognizing and interpreting the information available to him.

RECOMMENDATIONS

NEAR TERM.

1. Implement present video disc and cathode-ray tube (CRT) technology for electronically storing, displaying, and sequencing satellite images and National Weather Service (NWS) facsimile weather charts at flight service stations (FSS's).

2. Provide a prototype video disc, NWS facsimile interface, and interfacing for existing closed circuit television systems to determine how the system products should be provided to the specialist.

LONG TERM.

1. Initiate a program to investigate the application of the available image processing techniques to meteorological satellite images.

2. Investigate the application of monochromatic and color displays for satellite imagery.

3. A Federal Aviation Administration (FAA) representative should be assigned to monitor the Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) satellite program currently under the direction of National Aviation and Space Administration (NASA) and National Environmental Satellite Service (NESS).

4. The FAA should request NESS to produce a cloud tops analysis from the infrared satellite image data and the appropriate upper air temperature soundings.

5. Studies to determine cloud depth from reflected luminance should be funded or monitored with the goal of applying the technique to produce a cloud depth analysis for FSS use.

WEATHER RADAR.

Any action of the NWS next generation weather radar and weather radar products should be deferred until the study by the Aviation Weather Branch of Systems Research and Development Service (SRDS) has been completed and the questions concerning the use of weather radar in the Aviation Weather System have been resolved.

METEOROLOGICAL GRAPHICS.

1. Implement present technology to automatically derive graphics products from FAA Service A information.

2. Initiate a program to develop techniques and algorithms to automatically derive graphic products from the FAA Service A circuit.

3. Develop graphic display techniques to increase the rate of information transfer to the specialist.

4. Implement methods for overlaying meteorological graphics on satellite or weather radar imagery.

5. Utilizing a cloud tops analysis, a cloud depth analysis, the observed cloud bases, and cartographic information, develop techniques for displaying a plan view of clouds and terrain along flightpath segments.